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A Project in Two Parts: Developing Fire Histories for the Eastern U.S. and Creating a Climate-based Continental Fire Frequency Model to Fill Data Gaps

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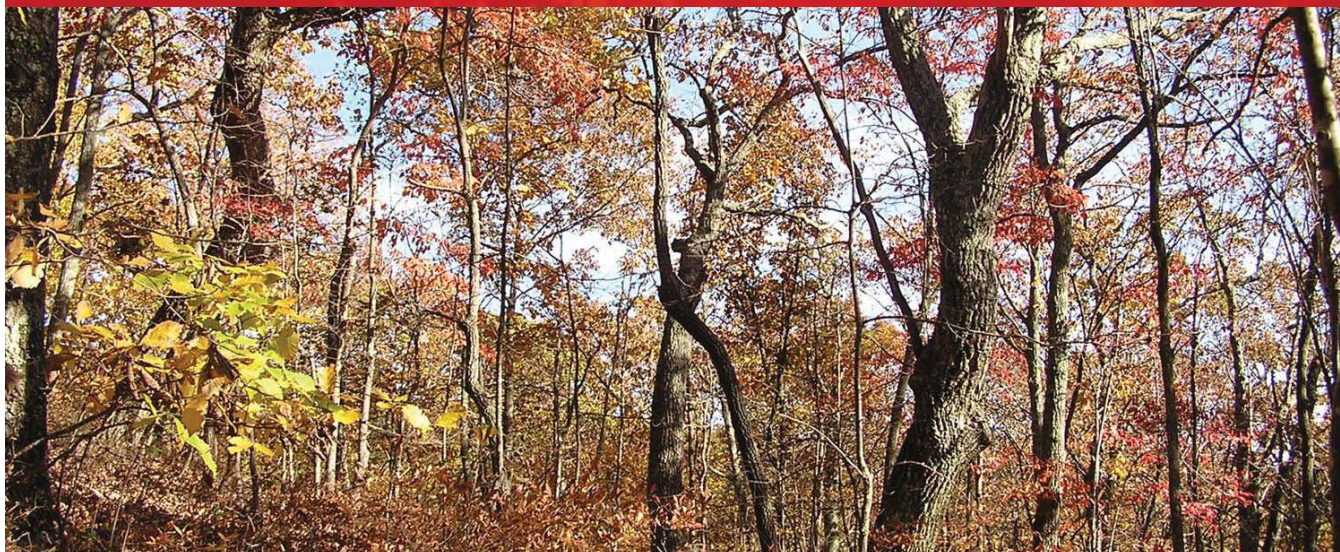
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Fire Science

Brief

RESEARCH SUPPORTING SOUND DECISIONS



Land Between the Lakes, Kentucky, where oak and pine provided eastern fire history data.

A Project in Two Parts: Developing Fire Histories for the Eastern U.S. and Creating a Climate-based Continental Fire Frequency Model to Fill Data Gaps

Summary

Tree-ring dated fire scars provide long-term records of fire frequency, giving land managers valuable baseline information about the fire regimes that existed prior to Euro-American settlement. However, for the East, fire history data prove difficult to acquire because the generally moister climate of the region causes rapid decay of wood. In an endeavor to fill data gaps, the research team collected fire scar data in the states of Alabama, Louisiana, Kentucky, Tennessee, Iowa, Wisconsin, and Michigan. The second part of the project used this newly collected fire history data combined with previously collected records to parameterize and calibrate a continental fire frequency model based on climate. The purpose of this model is to aid in understanding how climate constrains and drives fire regimes across the U.S. Large temporal and spatial gaps exist in our knowledge of continental fire regimes, but the new Physical Chemistry Fire Frequency Model (PC2FM) can assign a fire frequency to any square kilometer in North America. Even in places where there are no fire history data, the model can estimate with high precision how frequently fires occurred on average and what the upper and lower fire frequency limits were. The model's predictor variables were selected in part based on physical chemistry because, in its most basic form, fire is a chemical reaction. This model addresses how chemical reactions are controlled by temperature and precipitation, and how these variables combine to control combustion reactions. While previously developed fire regime models are typically based on specific vegetation communities, this model relies on climate variables as predictors. A benefit of a vegetation-free model is the applicability of the model to make predictions of fire frequency in situations where vegetation data are unavailable, not of primary interest, or when current vegetation might differ from historical or future. The research team's goal was to develop a climate-based model that can bring together and analyze disparate fire history data for: (1) a broad-scale characterization of past and future fire regimes and (2) assessing fire regime sensitivity to changes in climate.

Key Findings

- Fire history data are scarce in the eastern U.S., so the research team developed new fire scar histories in Alabama, Louisiana, Kentucky, Tennessee, Iowa, Wisconsin, and Michigan.
- The researchers used this newly collected fire history data combined with previously collected records to successfully parameterize and calibrate a continental fire frequency model based on climate. The purpose of this model is to aid in understanding how climate constrains and drives fire regimes across the continental U.S.
- The PC2FM can assign a fire frequency to any square kilometer in the country, which is particularly important in places where there are no existing fire history data.
- A benefit of a vegetation-free model is the applicability of the model to make predictions of mean fire intervals (MFI) in situations where vegetation data are unavailable or when current vegetation might differ from historical or future vegetation.
- This is the first model to synthesize disparate fire history information across North America and formulate a single set of historical fire frequency estimates based on the physical chemistry of climate.

Hunting for history

“We can use history to guide us into the future. What do the trees tell us?” asks Richard Guyette of the University of Missouri Tree Ring Laboratory, the project’s principal investigator. Tree-ring dated fire scars provide precise long-term records of fire frequency and fire-climate interactions from diverse forested sites across North America. For more than 30 years, these data—which provide both spatial and temporal insight—have been the foundation of hundreds of fire and ecosystem studies and are available for many types of ecosystems via international science archives and scientific publications.



Two fire scars in 67 years in a cold, wet, and snowy low elevation red pine ecosystem (Upper Peninsula of Michigan).

Fire history data give land managers valuable baseline information about past changes in fire regimes. Guyette explains, “Fire histories help to inform managers about how present day forests developed. Forests are generally slow to change, and having this long-term information on a major process such as fire that influences regeneration and growth gives managers a broader perspective on forest conditions and perhaps how they’ll achieve desired future conditions.” However, for the East, fire history data prove difficult to acquire. The particular types of tree species and the generally moister climate of the region both contribute to the rapid decay of wood, leaving few old trees and stumps from which to obtain this valuable historical record, thereby creating an obstacle for managers who rely on these data to develop fire and land management plans.

In an endeavor to fill these data gaps, the research team—funded by the Joint Fire Science Program—embarked on the first part of this two-part project and collected fire scar data in the states of Alabama, Louisiana, Kentucky, Tennessee, Iowa, Wisconsin, and Michigan. The project report, which can be found at http://www.firescience.gov/JFSP_Search_Advanced.cfm, gives details on specific site locations, number of years spanned by the tree-ring and fire scar record, years of fire events, fire frequency summaries (including MFIs), and study site details relevant to fire regimes. The fire history data collected through this project will be made publicly available through the International Multiproxy Paleofire Database (<http://www.ncdc.noaa.gov/paleo/impd/paleofire.html>).



Fire scars (red arrows) on live and dead red pine (*Pinus resinosa*).

Filling data gaps through a climate-based model

The second part of the project used this newly collected fire history data combined with previously collected records to parameterize and calibrate a continental fire frequency model based on climate. The purpose of this model is to aid in understanding how climate constrains and drives fire regimes across the continental U.S. In other words, the model estimates how climate “sets” the upper and lower limits of fire frequency and also how climate “pushes” the fire regime to a certain average fire frequency over long time periods.

Although much has been written and quantified over the last half century, there remain large temporal and spatial

gaps in our knowledge of continental fire regimes. In fact, most of the area of North America is without quantitative fire regime information. “Ideally,” explains Guyette, “all managers would have fire scar histories for the individual parcels of land that they manage; however, way more often than not, there’s just no fire history information there. It has rotted away, been consumed by fire, or there never were any old trees to keep record of fire scars. That’s where the model comes in.” In essence, the PC2FM can assign a fire frequency to any square kilometer in the country. Even in places where there are no trees, the model can estimate how frequently fires occurred on average and what the upper and lower fire frequency limits were. Spatially and temporally, the model can provide estimates in places and for periods in the past that have no fire frequency data.

A vegetation-free model

Fire history records have been the foundation of fire and ecosystem theories for years and have broad applications. Besides providing land managers with valuable baseline information about fire regimes prior to the Euro-American settlement period, they offer ecological insight into the plant distribution and succession that underpin ecosystem management and restoration. However, many forests and grasslands are undergoing drastic changes in species composition, fuels accumulation, fire frequency, and fire severity. Although previously developed fire regime models are typically based on specific vegetation communities, more recent modeling efforts have begun to include climate variables, such as temperature and precipitation, as predictors. “Vegetation wasn’t giving us all the answers we were looking for,” explains Guyette. “We specifically do not include vegetation in the PC2FM because our main interest was to parameterize climate’s influence on fire regimes.” Guyette points out that “in the end, it is climate that determines vegetation, not the other way around.”

A benefit of a vegetation-free model is the applicability of the model to make predictions of fire frequency in situations where vegetation data are unavailable, not of primary interest, or when current vegetation might differ from historical or future vegetation. For these reasons, there is great value in a predictive model that synthesizes existing fire history information and formulates mean fire intervals based on physical mechanisms—particularly climate. Guyette acknowledges that it’s not just vegetation that has been purposely left out of the model variables: “There are all kinds of variables that affect fire regimes, and we’re addressing climate only—not vegetation, not the frequency of human or lightning ignitions, not fire suppression, topography, or grazing, and so on. The important result is that our model has strong large-scale predictive ability because climate is the most important long-term factor influencing fire regimes.”

A dual-purpose model

The research team’s goal was to develop a climate-based model that can bring together and analyze disparate

fire history data for: (1) a broad-scale characterization of past and future fire regimes and (2) assessing fire regime sensitivity to changes in climate.

The team began by providing site-level quantitative fire scar history information in regions of the eastern United States, an area where this information had been previously lacking. This endeavor also begins the process of incorporating existing, new, and future fire regime information from diverse climates throughout North America into the PC2FM. The PC2FM model calibration and validation required empirical datasets as well as a solid underpinning in physical chemistry. The PC2FM is linked to a Geographic Information System and, using geospatial climate data as inputs, is capable of generating coarse-scale maps of fire regimes across the continental U.S. (see figure on next page).

Taking it a step further, a model that predicts fire frequency based on climate should allow for the projection of how climate conditions of the distant past or future influence fire regimes. Temperature and precipitation interact in complex ways to force limits on fire frequency. For example, PC2FM model results indicate that in regions with hot (>24° Celsius [>75° Fahrenheit]) and dry (<64 centimeters [<25 inches] precipitation) climates, increases in temperature will lead to decreasing fire frequency due to lower fuel production. The effect of increasing temperature is different for wetter regions, where increased temperature will reduce fuel moisture—an important fire variable. In essence, a broad change in climate, such as increasing temperature, will have variable effects across the U.S. “We can measure different temperature and precipitation influences for any region with this model,” explains Guyette.

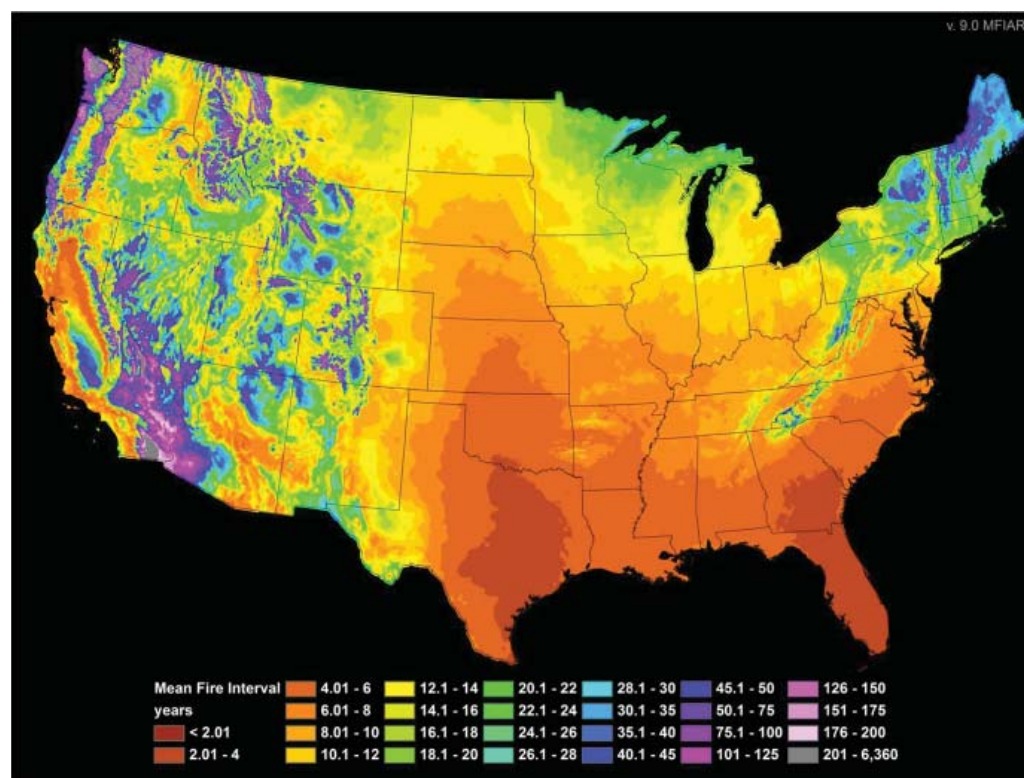
Model specifics

The researchers developed and calibrated the PC2FM for the time period prior to widespread Euro-American influence (before approximately 1850) to minimize the major post-settlement anthropogenic effects on fire frequency, such as fire suppression, industrial agriculture, domestic grazing, and the introduction of invasive and exotic vegetation. In addition, they used annual climate means rather than monthly or seasonal means in the model for two main reasons. First, fire seasons vary across the continent, and second, it’s the effects of temperature and precipitation throughout the course of the entire year that can control fuel production and decay.

PC2FM predictor variables were selected and developed based on fire ecology and physical principles. The team chose three main MFI predictor variables. Mean maximum temperature comprises the average of all high temperatures for every day of the year; this variable proved more suitable than *mean average temperature* since most fires occur during the time of daily maximum temperature. Mean maximum temperature and *mean annual precipitation* constitute the two “biggies” in terms of model variables. Also included, but of less significance, is a moisture index, which is a model component that addresses the interaction

between temperature and precipitation (that is, how temperature affects moisture, or what results from their differences).

climate-based fire frequency model, the researchers used the principles of physical chemistry—along with fire history data—to develop, calibrate, and validate the new model.



Climate-modeled MFIs for a historical period (~1650–1850).

Chemistry, climate, and combustion

The model's predictor variables were selected based on fire ecology and physical principles. At this point we need to step back and remember that first and foremost, wildland fire is a chemical reaction. Guyette elaborates, "Before Smokey the Bear, before the concept that this vegetation burns more frequently than that vegetation, is the fact that fire is a chemical reaction." This model addresses the most basic relationships of fire: how chemical reactions are controlled by temperature and precipitation, and how these variables combine to control combustion reactions.

To incorporate physical principles in the model, the researchers employed Arrhenius' equation. Used in physical chemistry, it describes reaction rates based on environmental and chemical variables. The researchers applied this equation to the landscape-scale by equating reaction rate with mean fire interval. They assume that the drivers of the reaction rate (MFI) are things like fuel production and decay rates and combustion reaction rates, variables that are influenced by climate conditions.

Scaling this concept up to ecosystems, which are intricately influenced by temperature and precipitation, requires much modeling effort because many important physical-chemical factors are responsible for controlling the spatial and temporal history of fire regimes. In other words, fire regimes are constrained by climate through the physical chemistry of ecosystems. So, in their endeavor to create a

represented by millions of acres of land without any known fire histories. So, the PC2FM is not wholly dependent on spatial distributions of the empirical data, but rather is dependent on data that represent the wide range of reaction conditions specific to various climates.

Climate variance, then, is key to the model's predictive abilities. The ecology and chemistry of fire—from hot-desert to cold-glacial environments—provides the model with the wide range of temperature and precipitation variance needed to produce more accurate estimations of fire frequency. These two examples from opposite ends of the potential variation in climate serve as critical input to the model; however, Guyette explains that "the areas that give us the most important information are those with really long fire frequency intervals, such as the Pacific Coast rain forest, and areas with short intervals, such as the southeastern U.S.—because fire intervals from extreme climates help define the effects of physical chemistry on fire regimes.

Future (and immediate) endeavors

The outlook is exciting. The PC2FM presents a new way of thinking about fire regimes—how they are constrained and driven by climate. And future investigation opens up further possibilities.

One interesting area of future research involves global climate models, or GCMs. Using temperature and precipitation, GCM output can be input into the PC2FM model to derive estimates of fire regime changes for, say,

The model has both a process component (based on the laws of physical chemistry) and a probabilistic component (based on statistical analysis) that translate the physical chemistry of ecosystems into quantitative equations. A fundamental aspect of process models is that they are not restricted in space and time. Combustion reactions are held by the same laws of physical chemistry today as they will be tomorrow, and regardless of whether the reactions are taking place in Alaska or Florida. For this reason, climate-based fire frequency predictions can be made beyond the realm of available data that, in this case, is

the year 2100. Granted, this doesn't take into account other variables, such as the spread of invasive species or land-use changes, but considering climate only, reasonably accurate estimates of climate's influence should be possible.

Of utmost importance, however, is the immediate need to collect additional fire scar data from decaying wood and dying older trees in eastern North America. In the eastern U.S., many trees with fire history information are dying from "old age," disease, and insects, and preserved pine and oak stumps are crumbling rapidly, as well. Guyette explains, "What's there is decaying, and we're losing that fire and forest history because we can't get out there and collect it fast enough." Furthermore, many trees in the East that extend significantly back prior to Euro-American settlement are beginning to die because they are reaching their maximum life-spans. Guyette continues, "We just don't currently have the support to go in and sample them to determine the fire history." Regarding the collection of fire scar data before it disappears, Guyette emphasizes: "As fire historians, this is probably the most important thing we do. Some people might say the modeling is the critical effort, but I disagree. What's needed immediately is to get out there, get the wood, date it, and perhaps preserve it for the future so that somebody a hundred years from now can use it. But right now it's dying; this history will be gone in a few decades, and it will be gone forever."

Lastly, the success of this project indicates that more effort towards understanding climate linkages to fire regimes will be of further value in both past fire regime reconstruction and in future fire regime projections. The value of models and data that can answer questions regarding fire and global changes—such as about temperature, CO₂, and human population—is becoming increasingly relevant to society and natural resource management. Thus, models like the PC2FM as well as more empirical data such as fire scars are needed to inform scientists, managers, and the public about the ecology and significance of fire, giving us valuable information on how, where, and how often fires once burned...and how, where, and how often they may burn in years and climates to come.

Further Information: Publications and Web Resources

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Management Implications

- The fire scar history data collected by the research team provide quantitative local to regional scale estimates of fire frequency for the East that can be used to assess the present state of ecosystems, vegetation and fuels, and species.
- Fire history reports have been provided to managers at Land Between the Lakes National Recreation Area, Daniel Boone National Forest, Talladega National Forest, Chequamegon-Nicolet National Forest, and Kisatchie National Forest for use in fire regime assessments, public education, restoration, and prescribed fire planning.
- There is an urgent and immediate need to collect additional fire scar data from decaying wood and dying older trees, particularly in eastern North America. Managers can use PC2FM estimates and maps of fire regimes as a scientifically-based means of arriving at likely fire frequencies and other fire regime characteristics. With more specific local fire regime information, these coarse-scale estimates may then be lengthened or shortened based on specific area conditions such as topography or ignition rates.
- A benefit of a vegetation-free model is the applicability of the model to make predictions of MFIs in situations where vegetation data are unavailable or when current vegetation might differ from historical or future vegetation.

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Scientist Profiles

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